

Observation of NLIW in the South China Sea using PIES

David M. Farmer
Graduate School of Oceanography (educational)
University of Rhode Island
Narragansett, RI 02882
Phone: (401) 874-6222 fax (401) 874-6889 email: dfarmer@gso.uri.edu

Award Number: N000140710265

LONG-TERM GOALS

To study the mechanisms of generation, evolution and propagation of nonlinear internal waves [NLIW] in the vicinity and west of Luzon Strait in the South China Sea, making use of pressure equipped inverted echo sounders.

OBJECTIVES

Our objectives are (1) to observe the internal tide propagating west of Luzon Strait and its progressive evolution in shape and speed as it traverses the South China Sea under the influence of nonlinearity, non-hydrostatic effects, rotation, topography, currents and stratification, and (2) to interpret the results in with the help of models that incorporate these effects.

APPROACH

Our approach involved deployment of four modified pressure equipped inverted echo-sounders [PIES], set up to transmit every 6s. The PIES measures the return acoustic travel time from sea-floor to surface, which is modified by variations in the local stratification resulting from passage of internal waves. Knowledge of the background stratification is provided by CTD casts. Time series measurements of the acoustic travel time then provide a basis for inferring the first mode internal response. Nonlinear non-hydrostatic models can be used to interpret the evolution of the waves as they pass successive measurement sites. Additional modeling is used to explain the generation of the internal tide measured close to the Luzon sill.

WORK COMPLETED

Four PIES were deployed in April 2007 in the South China Sea in a line stretching west northwest from the narrow trench just west of the Luzon sill the 600m contour, as shown by red dots in Figure 1. Two blue dots show the locations of two PIES deployed during a pilot study in 2005. The 2007 deployments were recovered in July and the three easternmost moorings redeployed for recovery in October 2007.

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE 30 SEP 2007		2. REPORT TYPE Annual		3. DATES COVERED 00-00-2007 to 00-00-2007	
4. TITLE AND SUBTITLE Observation Of NLIW In The South China Sea Using PIES				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) University of Rhode Island, Graduate School of Oceanography, Narragansett, RI, 02882				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES code 1 only					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 6	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

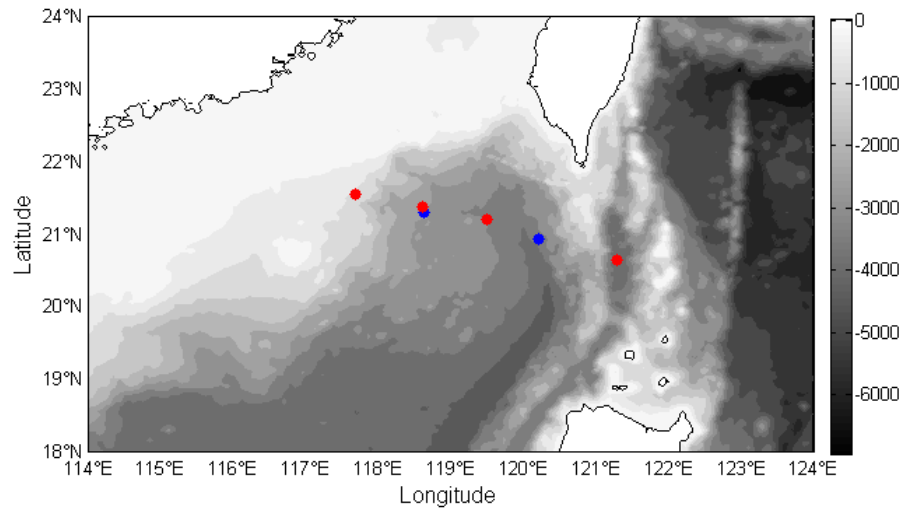


Figure 1. Chart showing locations of PIES deployed in South China Sea in 2005 (blue) and 2007 (red).

The westernmost PIES appears to have been tilted on deployment or otherwise adversely affected, possibly due to partial burying by wave-sediment interaction on the sloping terrain. It did not immediately rise to the surface when released in July, but was recovered a few days later some distance to the northeast and returned unharmed. The data from this instrument was not complete. Data from all but the westernmost mooring, for the April-July period have been processed and subjected to preliminary analysis. Key individuals involved in this project also include Erran Sousa (URI), responsible for technical aspects of deployments and recovery, Jae-Hun Park (URI) for assistance in implementing models, student Li Qiang (URI), and Karl Helfrich (WHOI) who has provided important theoretical support.

WORK COMPLETED

Four PIES were successfully deployed in the South China Sea, three of which returned good data. The instruments were redeployed on recovery. Data processing is well underway. Comparison of the results with theoretical models has been carried out.

RESULTS

Figure 2 shows a 7 day section of acoustic travel time observations from all but the westernmost PIES for a 7 day period in April, together with a time series of the predicted tidal current at Luzon Strait. The presence of high frequency nonlinear internal waves is apparent during the period 16-22 April, especially at the westernmost of the three moorings A3.

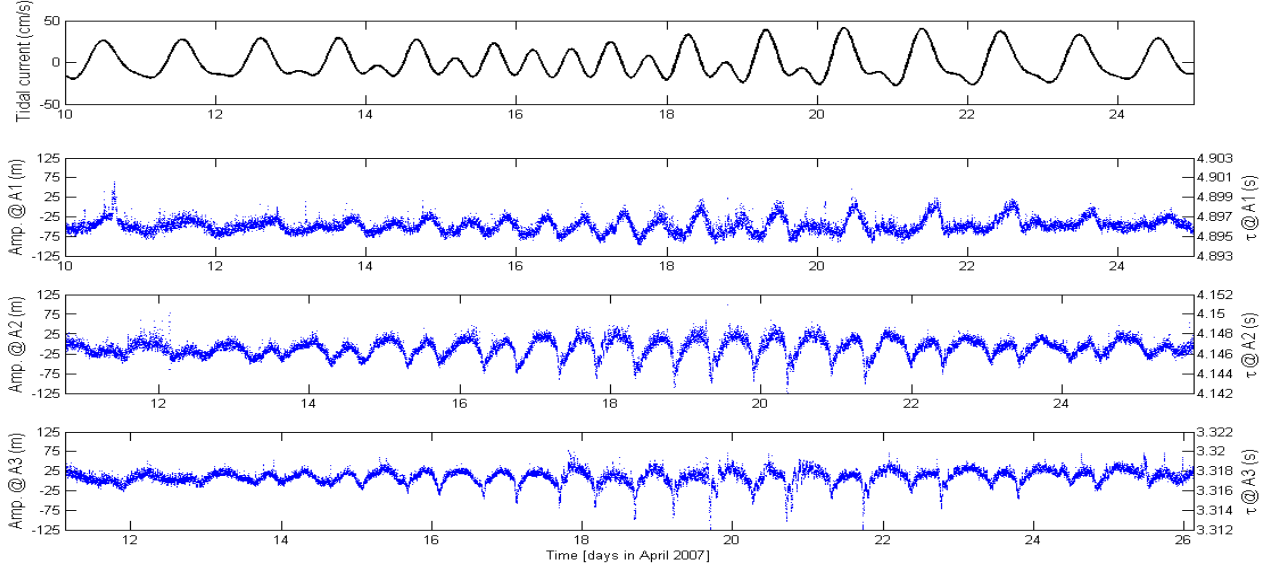


Figure 2. *Top panel: Predicted tidal current for 18-25 April 2007 at Luzon Strait (presumed generation area for the internal tide). Lower panels, time series of the PIES signal showing internal tide evolving as it crosses the South China Sea, with NLIW forming, especially during the period 16-22 April.*

Generation of the internal tide was analyzed with Hibiya's (1986) model and a representation of the Luzon Strait sill. This very simple model produced a reasonable first order prediction of the internal tide at A1, suggesting that strongly nonlinear processes are not dominant in the generation region. This is consistent with lack of obvious signs of NLIW at our easternmost mooring (A1) and favors an explanation of NLIW generation through progressive steepening of the internal tide into a shock front that disperses into a nonlinear wave train.

An important part of our analysis is focused on this evolution. We have made use of Helfich's 2007 two layer nonlinear dispersive rotating model to explore these effects. A key element of this effort is determination of the role of rotation, which inhibits steepening by dispersing energy into internal inertial waves. This effect would be more pronounced for a diurnal than a semi-diurnal wave at this latitude, as is readily demonstrated in model calculations, but the problem is made more subtle by the mixed character of the tide. We used a linearization of the boundary condition to force the model with our measurements at A1, and then compared the prediction with our observations at A2 and A3. Figure 3 shows the resulting comparison.

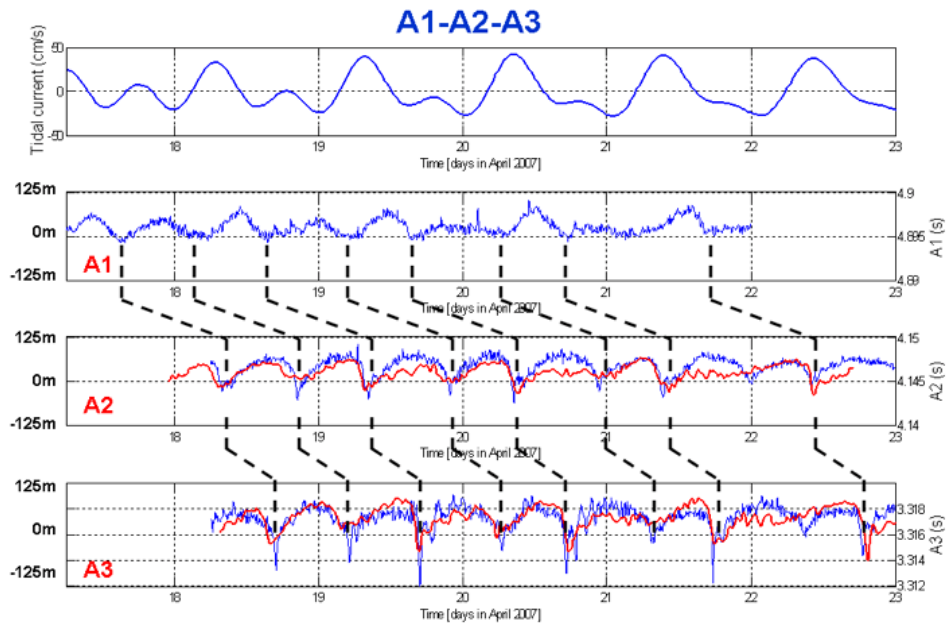


Figure 3. *Top: predicted tidal forcing at Luzon sill. Below: Vertical displacement first mode maximum streamline displacement inferred from PIES observations (blue). Prediction from Helfrich (2007) shown in red.*

IMPACT/APPLICATIONS

Our observations have provided essential data for establishing the mechanisms of NLIW generation west of the Luzon sill. It appears that high frequency NLIW are not generated right at the sill, but evolve through nonlinearity and dispersion as the internal tide propagates west. However, rotation has an important effect in dispersing energy into inertial modes and must be included in order to develop good predictions. These observations have sufficient detail to test rotational models for NLIW and thus contribute to better predictions of appearance and behavior.

RELATED PROJECTS

ONR project - Nonlinear Internal Waves: Test of the Inverted Echo Sounder.

REFERENCES

Hibiya, Toshiyuk, 1986, Generation mechanism of internal waves by tidal flow over a sill, *Journal of Geophysical Research*, Volume 91, Issue C6, p. 7697-7708

Helfrich, Karl, 2007, Decay and return of internal solitary waves with rotation, *Physics of Fluids*, 19, 026601.

PUBLICATIONS

Farmer, D., Park, J.H., Li, Q., and Ramp. S., 2006: Inverted Echo-Sounder Observations of Nonlinear Internal Waves in the South China Sea, AGU Fall meeting, 2006.

Li, Q., Farmer, D., Helfrich, K., and Park, J.H., 2006: Generation and Propagation of Nonlinear Internal Waves in the South China Sea. AGU Fall meeting, 2006.